Jet Propulsion Laboratory
California Institute of Technology

http://www.jpl.nasa.gov/cubesat/missions/marco.php

Deployable Circularly Polarized UHF Printed Loop Antenna for Mars Cube One (MarCO) CubeSat

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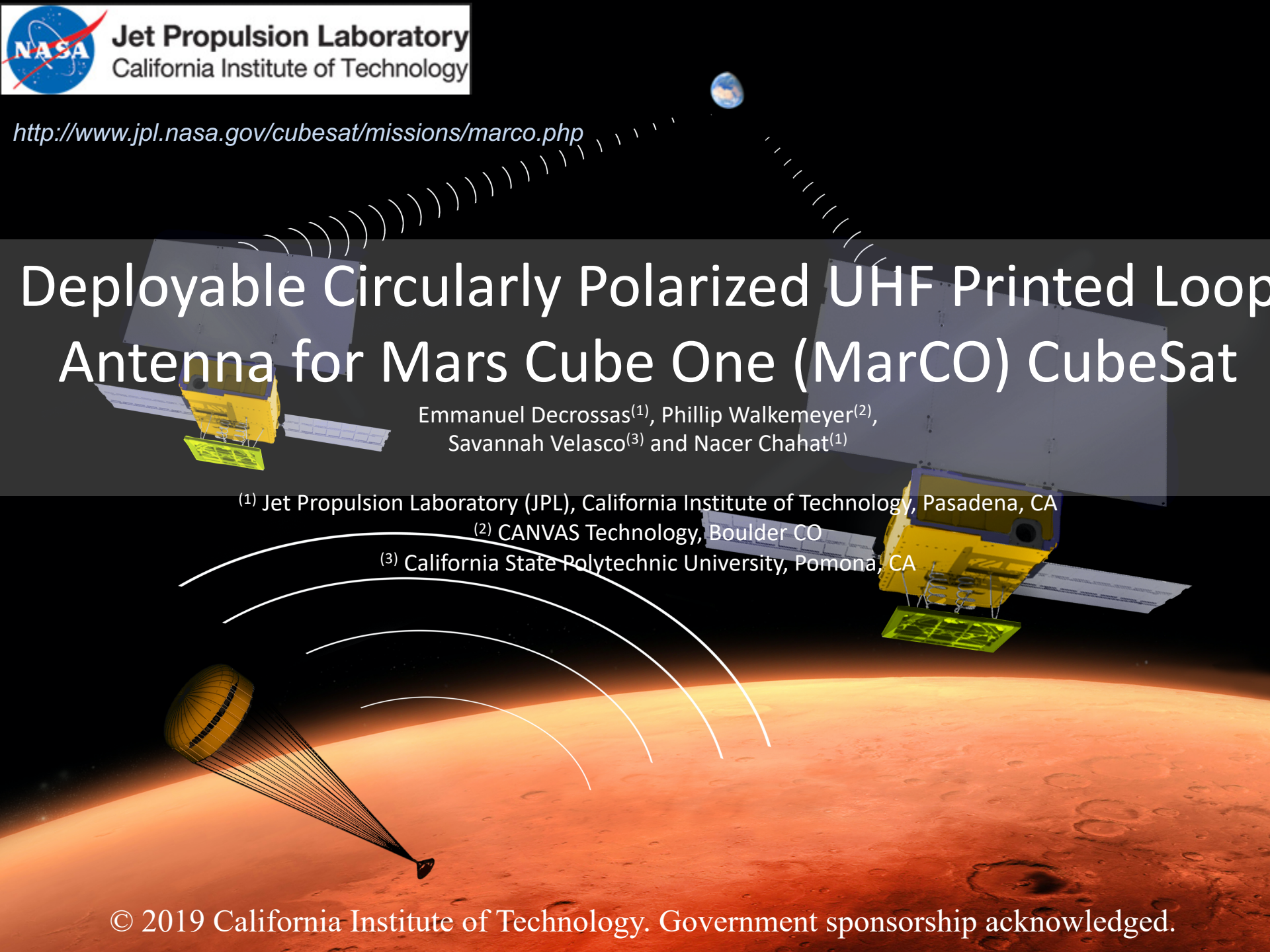
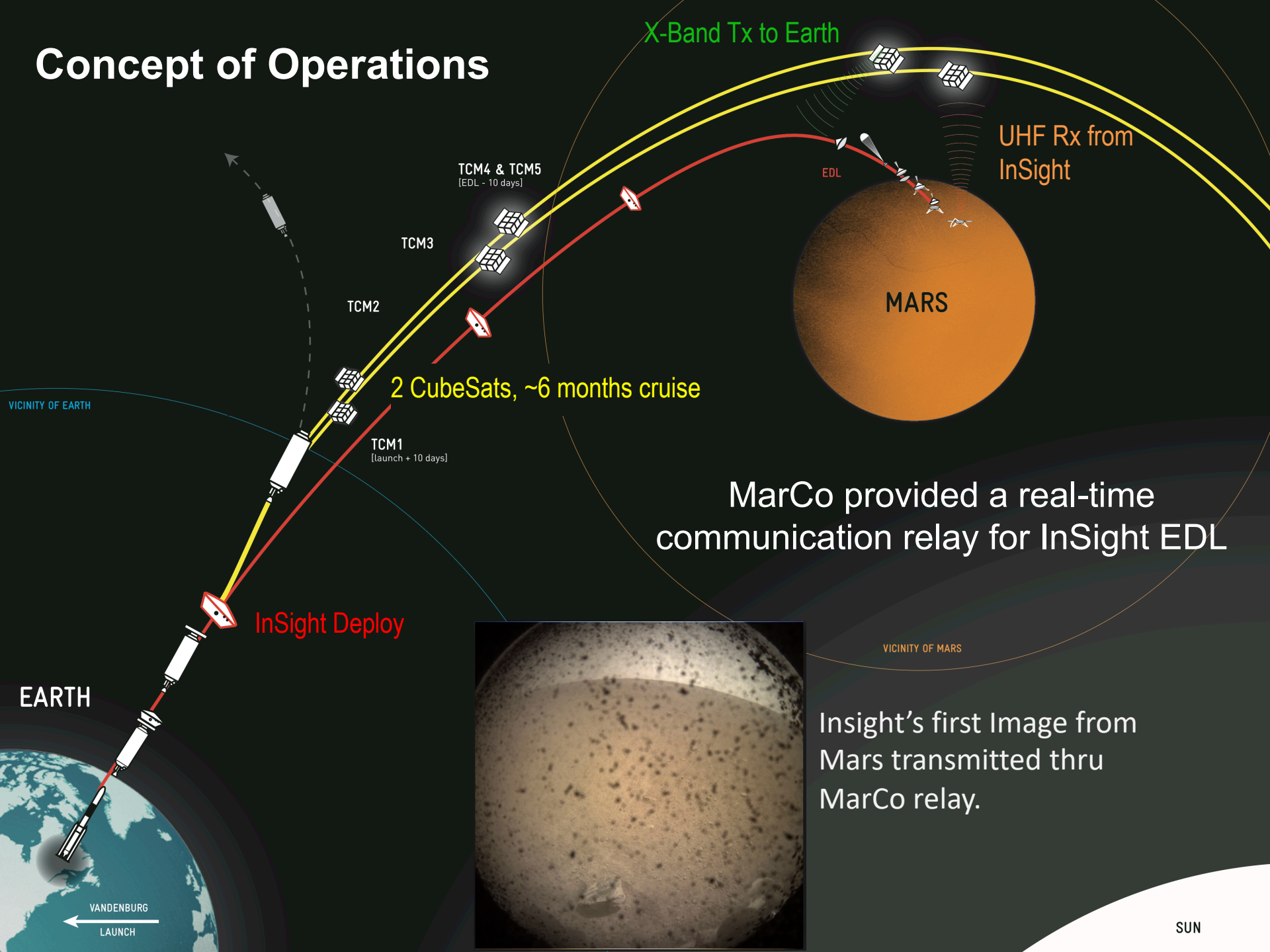


UHF Antenna

- Overview of UHF antenna design
  - Location on spacecraft
  - Purpose and operation of antenna
- Requirements
  - UHF antenna RF Requirements
  - Volume / Stowage Requirements
  - Deployed antenna alignment requirements
  - RF interface requirements
  - Electrical Requirements for deployment
- RF design detail
  - Maturity of the concept
  - Stowage and deployment scheme
  - UHF Loop design
    - → Layout / construction
    - → Predicted performance and measurements
- Conclusion

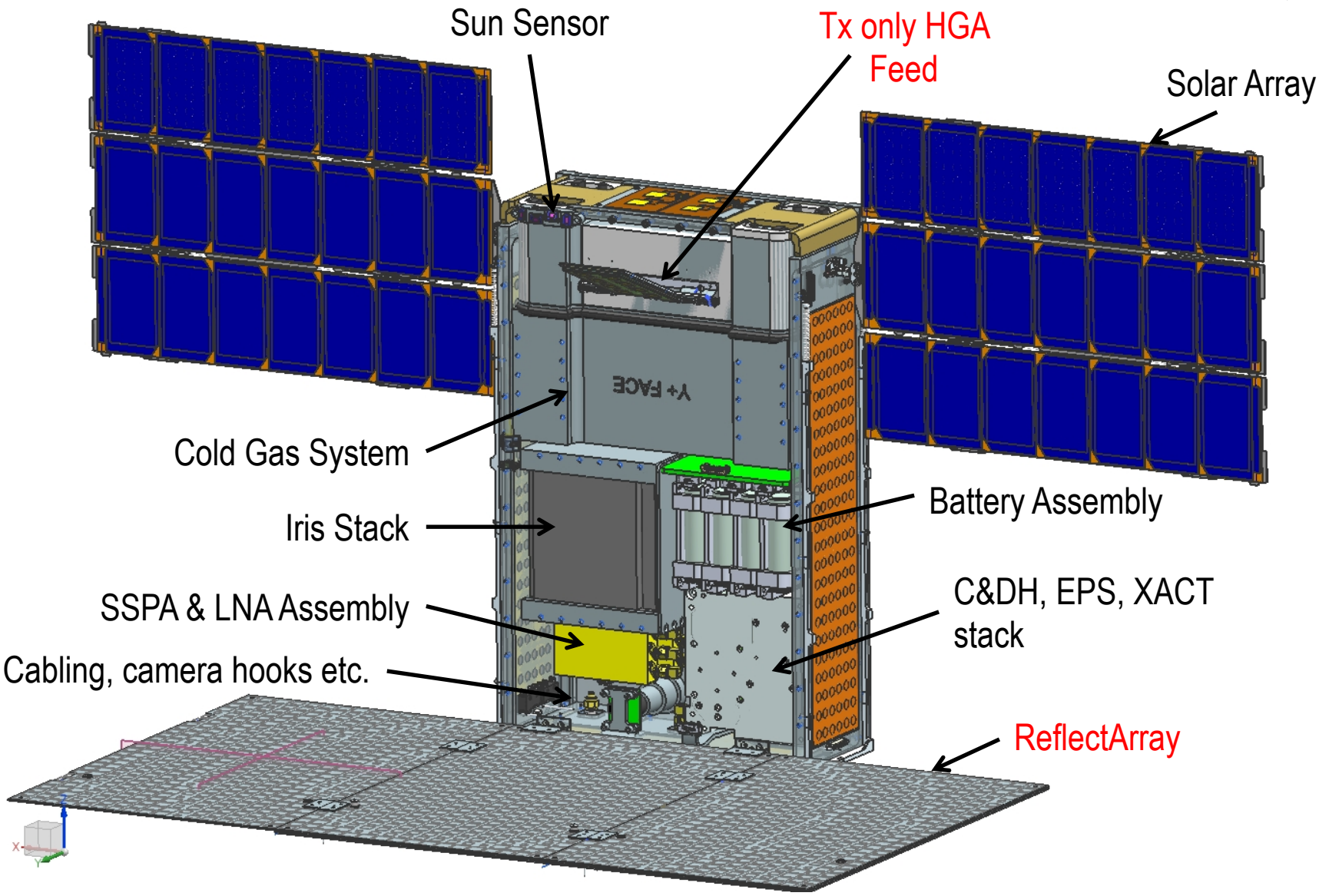
Concept of Operations



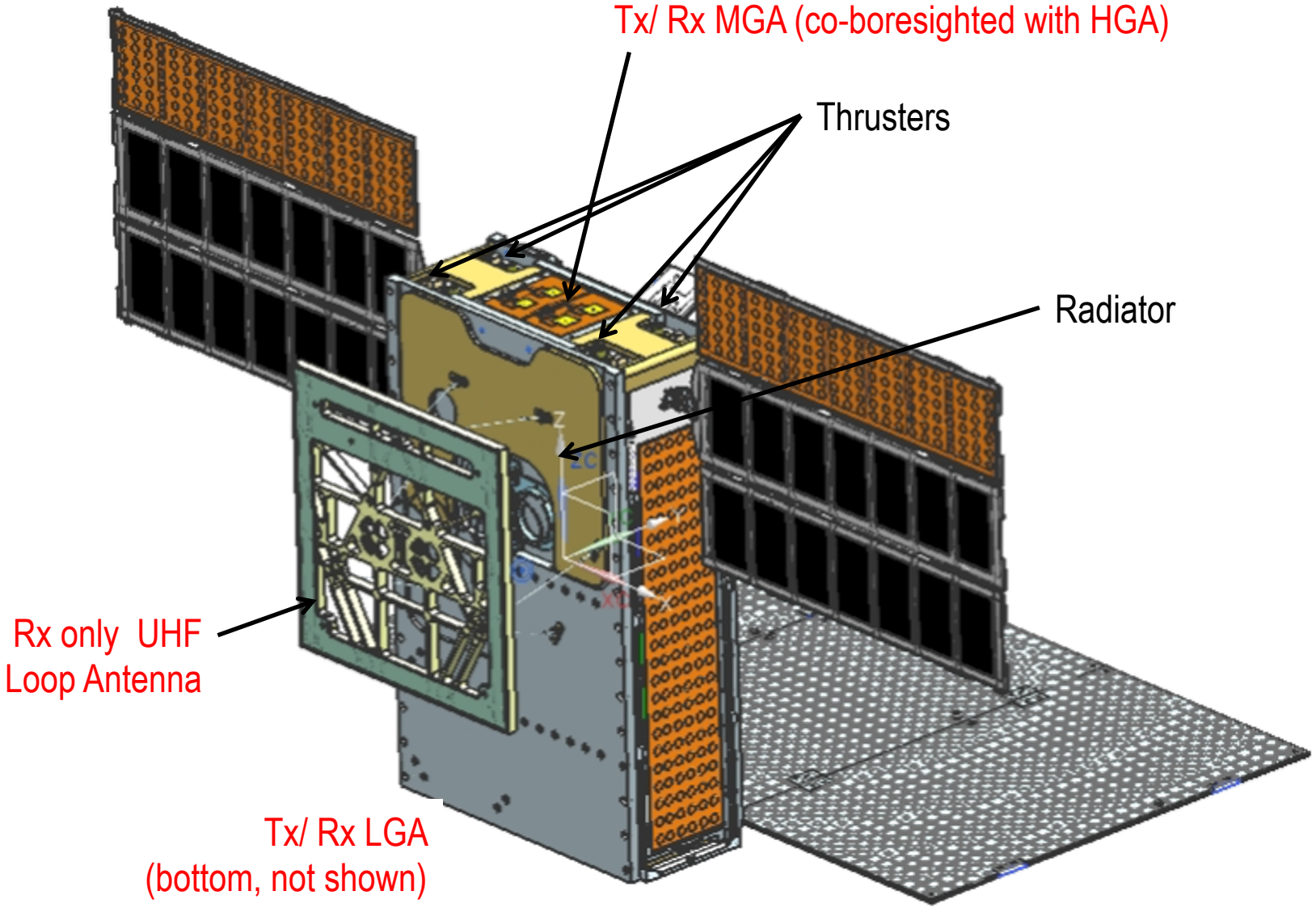
MarCo provided a real-time communication relay for InSight EDL

Insight's first Image from Mars transmitted thru MarCo relay.

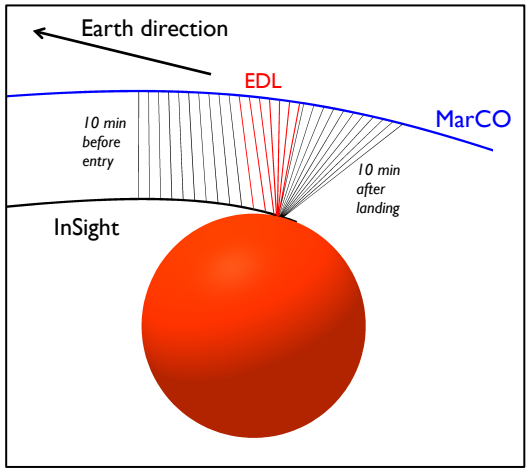
Mechanical Configuration: Deployed



Mechanical Configuration: Deployed



Purpose and operation of the UHF antenna



Arrays pointed at +/- 5° (1σ) when recharging

Z-axis is in the along-track direction (velocity vector)

To Earth

To Sun

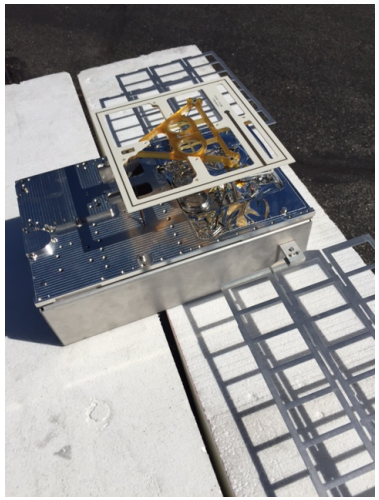
22.75°

45°

To InSight

+/- 30° (3σ)

11° at touchdown (T_0), Ranges from -10° to 11° from T_0 – 16 minutes to T_0



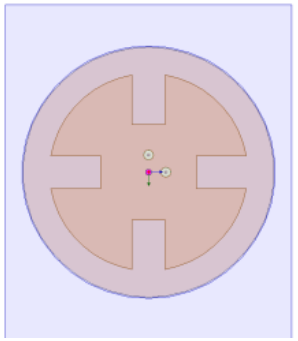
InSight

Max Range ~ 3500 km

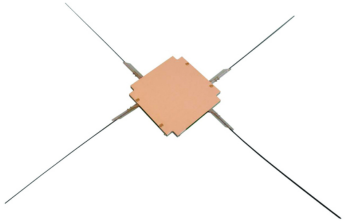
Requirements

	Electrical	Requirements	Measurements
UHF-1	Center Frequency	401.585625 MHz	401.585625 MHz
UHF-2	Bandwidth	> 100 KHz	20 MHz
UHF-3	Gain within ±30° of boresight	> 2.5 dBic	>2.5 dBic
UHF-4	Polarization	RHCP	RHCP
UHF-5	Cross Polarization Discrimination (XPD) ±30°	> 5 dB	>10 dB
UHF-6	Return loss	> 14 dB	> 25 dB
	Mechanical		
UHF-7	Stowed volume allocation	200x200x16 mm^3	200x200x12 mm^3
UHF-8	Total Mass	< 400 g	< 160 g
UHF-9	Tip/tilt error deployment	<± 2°	< ±0.43°
UHF-10	Lateral offset error	0± 2mm	< ±1 mm
UHF-11	Vertical offset	84mm +2mm/-0mm	85.66mm ±0.11mm
UHF-12	Connector	SMA female	SMA female
	Burn wire mechanism		
UHF-13	pairs of burn wire leads	yes	yes
UHF-14	DC voltage/current applied	1.6 A for 2-10 sec	1.6 A for 2-10 sec

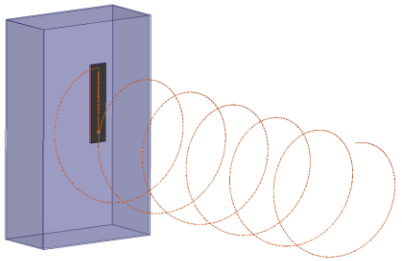
Design options



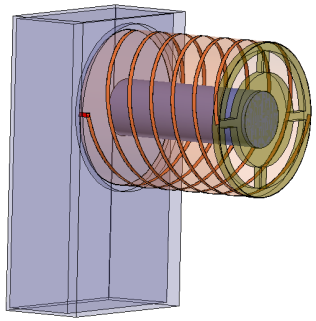
- Patch (non deployable): gain requirement cannot be met
- Deployable options.
  - Dipole antenna
    - → Gain requirement cannot be met.



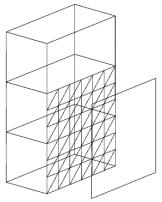
  - Unifilar helix antenna
    - → Antenna is too long to meet the requirement



  - Quadrafilar helix antenna.
    - → Meet the requirement
    - → Mechanical deployment: “jack in the box”
    - → Requires power divider, hybrid, cannot be fit in the S/C

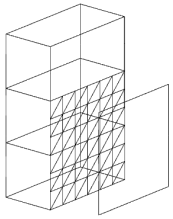


  - Wire Loop antenna (estimated gain 4 dBi)
    - → Meet the requirement
    - → Mechanical deployment based on hinges rotation is an issue.
    - → Requires power divider, hybrid, cannot be fit in the S/C

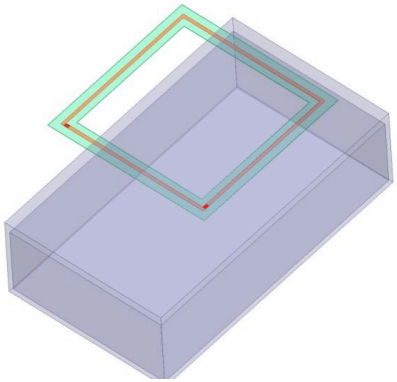


No commercially available antenna meets these stringent requirements

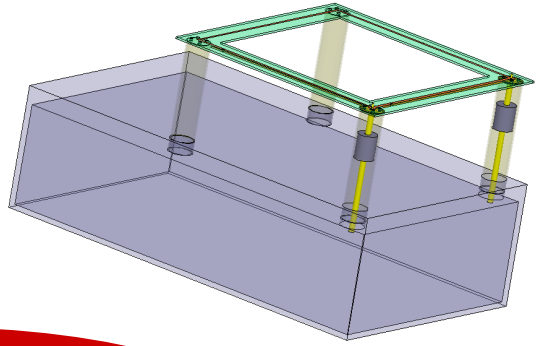
From concept to flight hardware



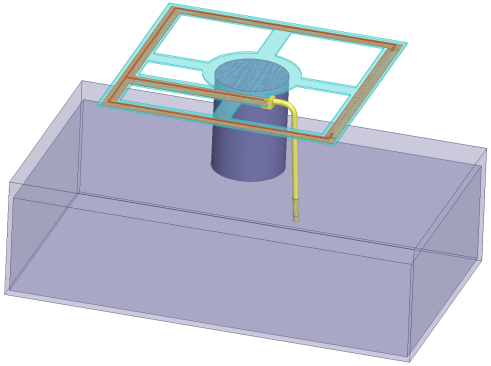
wired loop antenna (concept)



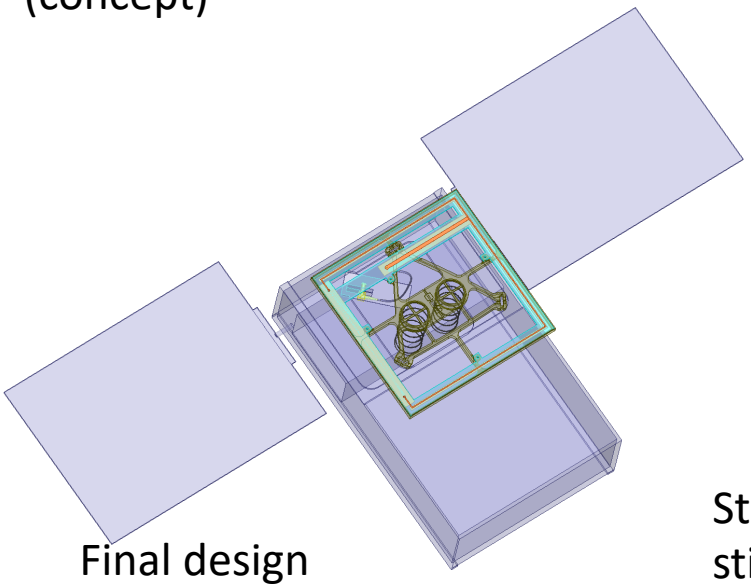
printed loop antenna



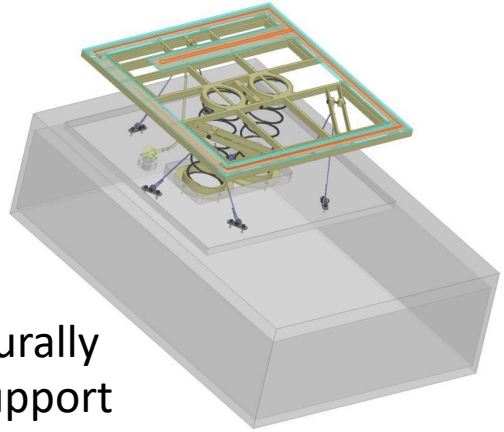
quadrature fed printed loop antenna



Jack in the box printed loop antenna, one feed



Final design



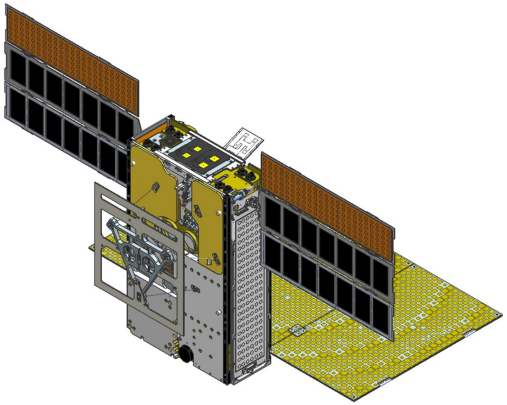
Structurally stiff support

Benchtop Deployment

Thermal Deployment at -60 °C

-60° C is the temperature expected of the cable during the deployment

UHF antenna pattern measurements



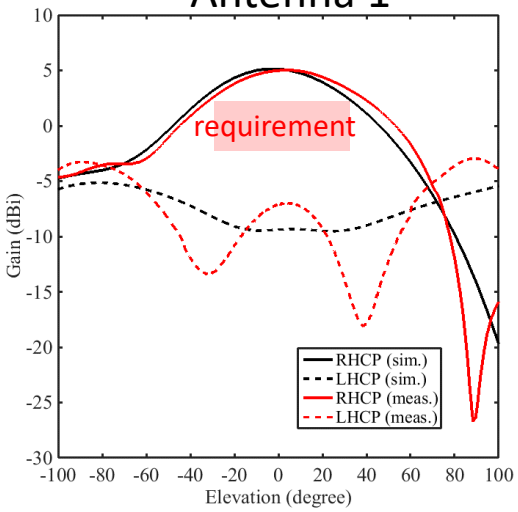
All antenna patterns are measured using the same setup. Only the printed loop antennas with their respective coaxial cable are substituted.

RF design detail

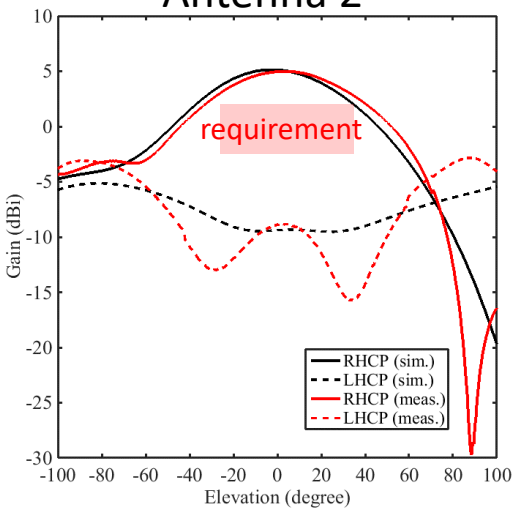
Requirement: 2.5 dBic Gain within ±30° of boresight

XPD 5 dB, RHCP polarization

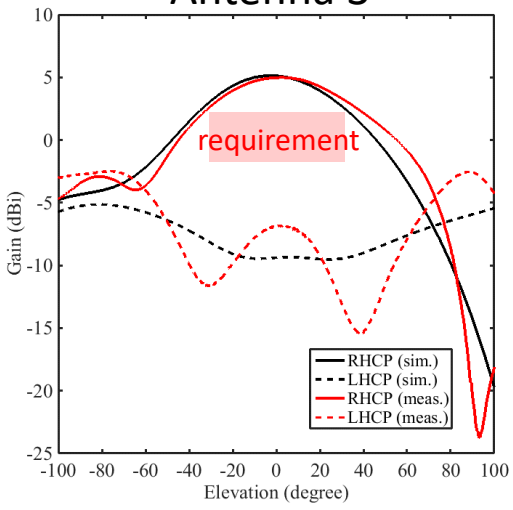
Antenna 1



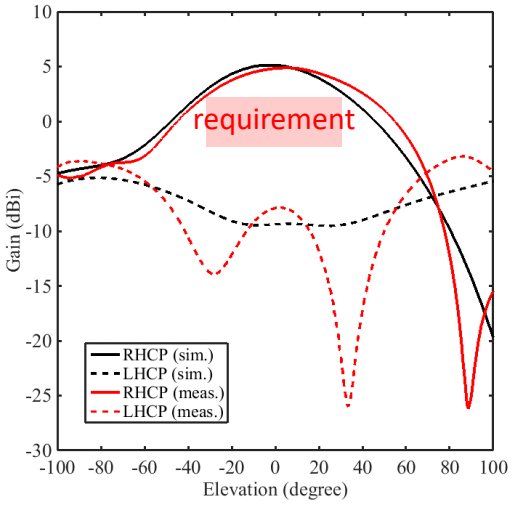
Antenna 2

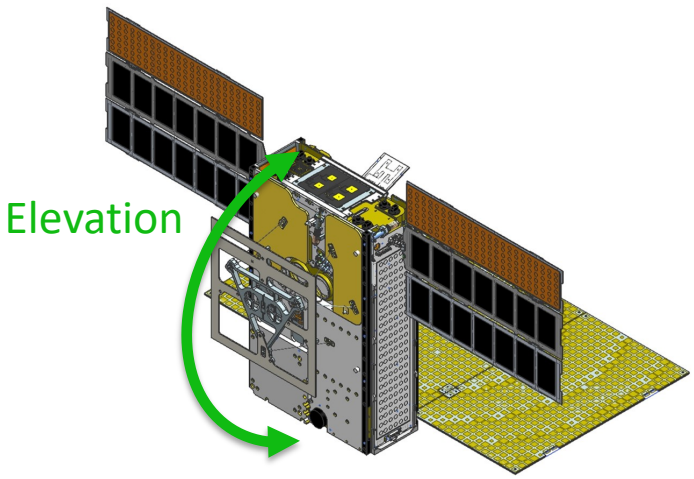


Antenna 3



Antenna 4



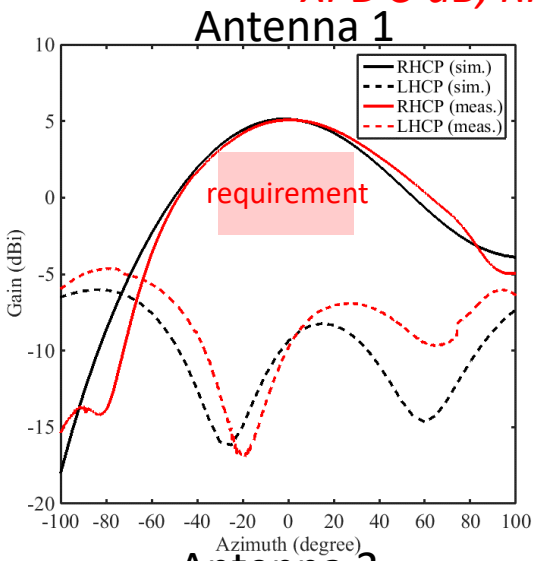


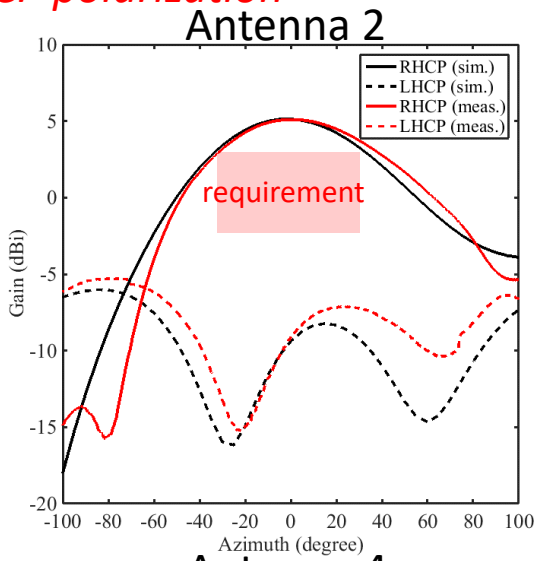
Measurements are realized after outgassing and thermal-cycling the antennas

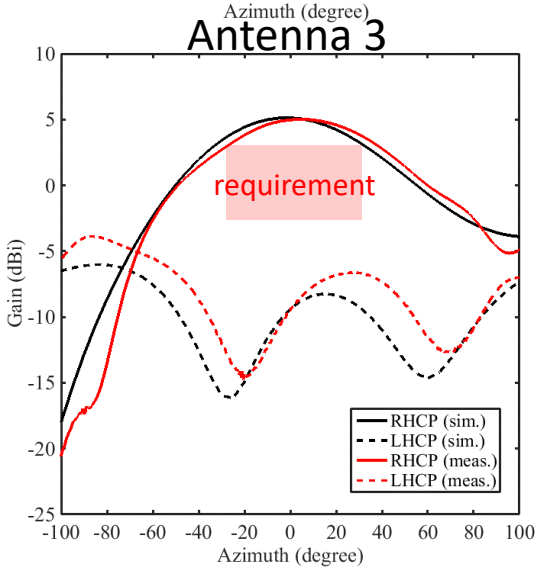
Measured Antenna Gain.

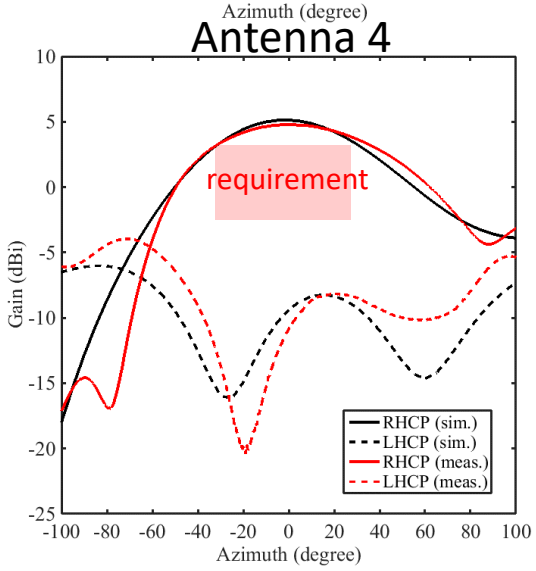
Requirement: 2.5 dBic Gain within ±30° of boresight

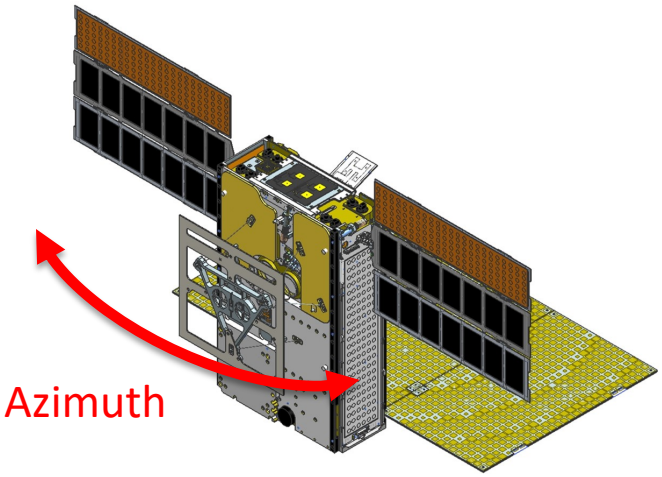
XPD 5 dB, RHCP polarization







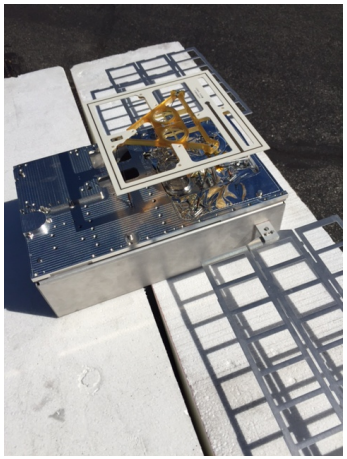


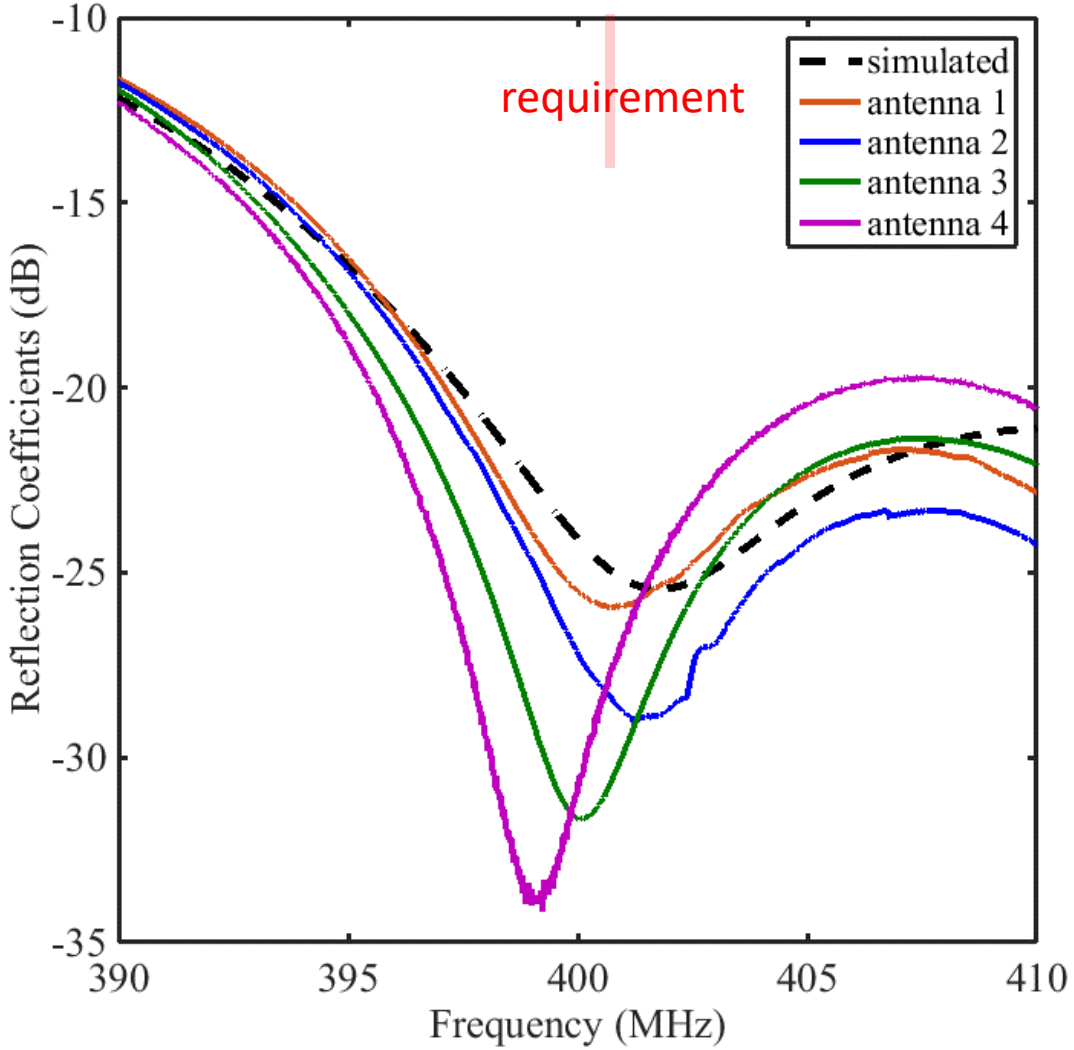


Measurements are realized after outgassing and thermal-cycling the antennas

Reflection coefficients

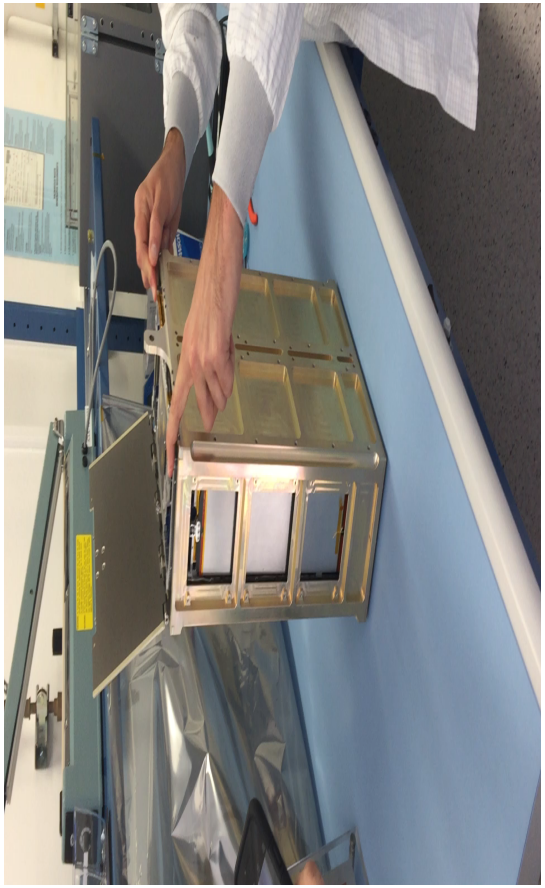
Requirement: Center frequency 401.585625 MHz, bandwidth >100KHz, return loss >14 dB





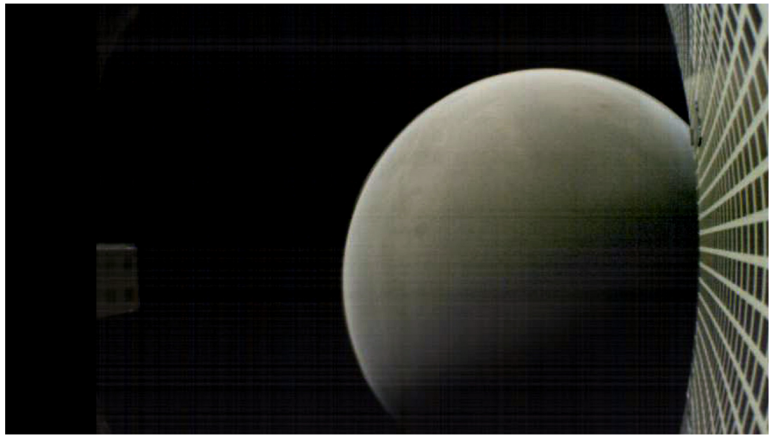
Conclusion

- The CubeSat in stowed configuration fits the box.
- 8 months from concept to flight hardware.
- Meet all requirements.
- Antenna delivered
- Successful mission.



NEWS | NOVEMBER 27, 2018

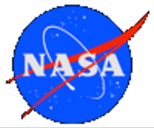
NASA Hears MarCO CubeSats Loud and Clear from Mars



MarCO-B, one of the experimental Mars Cube One (MarCO) CubeSats, took this image of Mars from about 4,700 miles (7,600 kilometers) away during its flyby of the Red Planet on Nov. 26, 2018. MarCO-B was flying by Mars with its twin, MarCO-A, to attempt to serve as communications relays for NASA's InSight spacecraft as it landed on Mars.Credits: NASA/JPL-Caltech

› Full image and caption

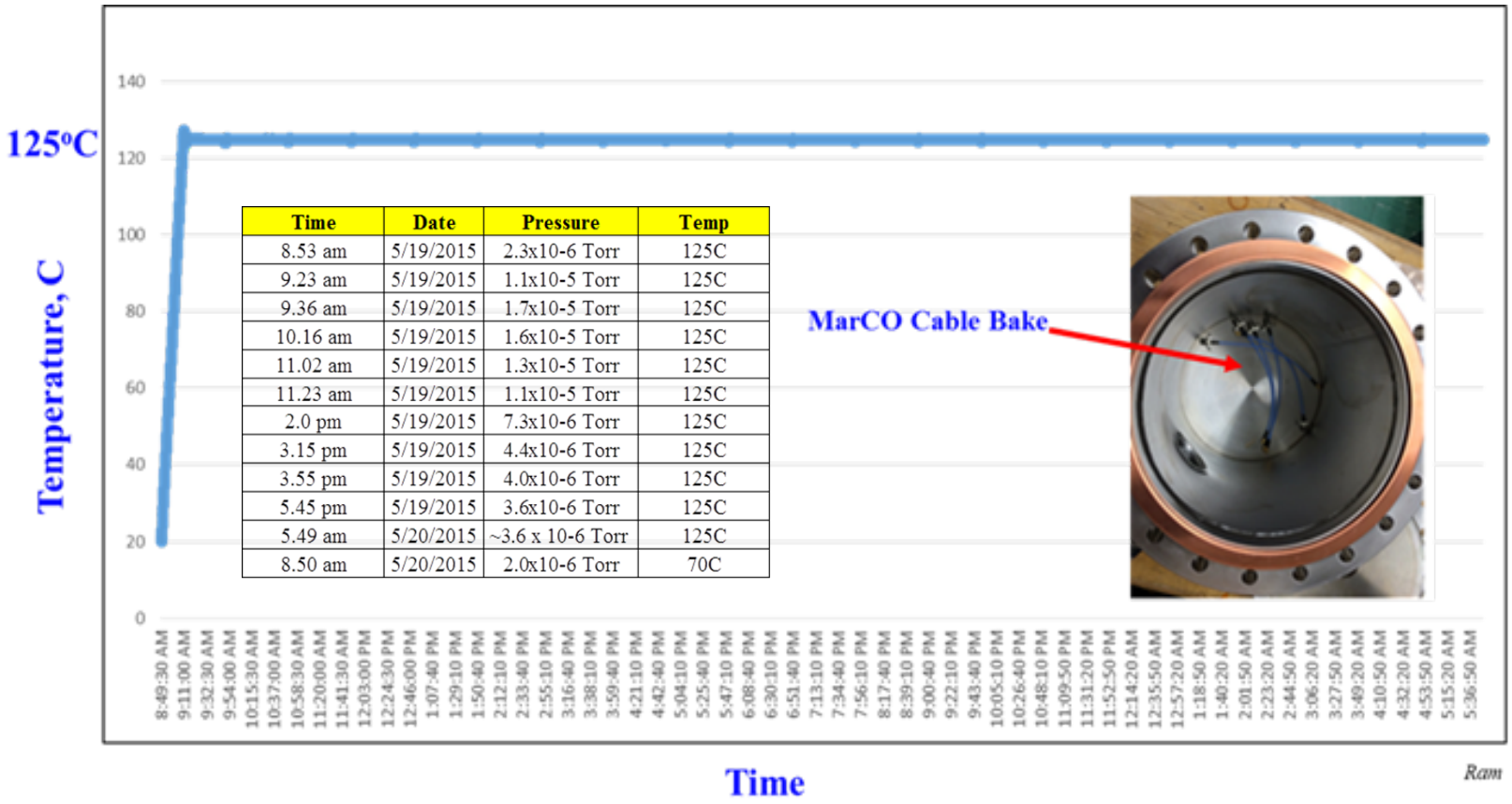
Reference article: https://www.jpl.nasa.gov/news/news.php?feature=7295



Backup slides

Outgassing coaxial cables

- **After bake out for outgassing @ 125° C for >10 hours, the measured insertion loss is 0.16 dB +/-0.01dB. (~23% degradation).**

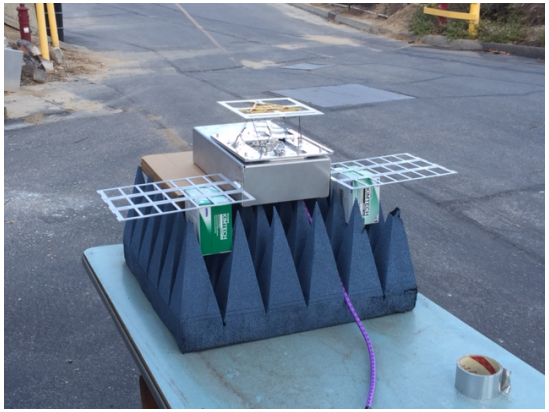


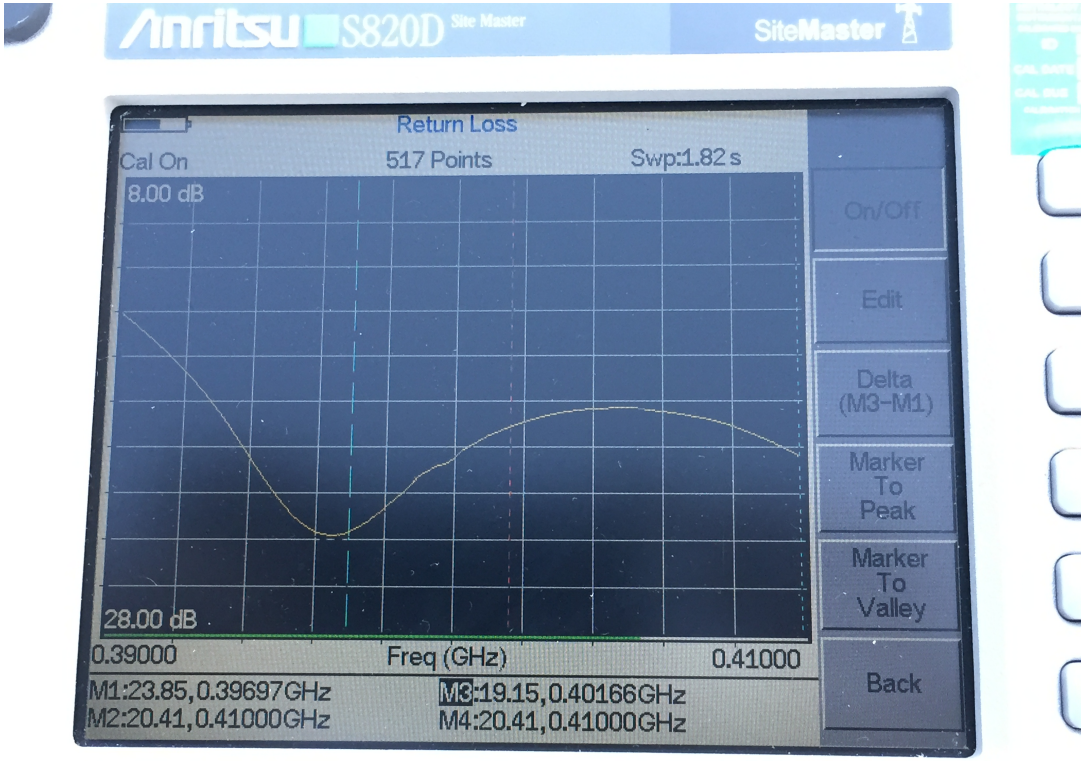
Time	Date	Pressure	Temp
8.53 am	5/19/2015	2.3x10-6 Torr	125C
9.23 am	5/19/2015	1.1x10-5 Torr	125C
9.36 am	5/19/2015	1.7x10-5 Torr	125C
10.16 am	5/19/2015	1.6x10-5 Torr	125C
11.02 am	5/19/2015	1.3x10-5 Torr	125C
11.23 am	5/19/2015	1.1x10-5 Torr	125C
2.0 pm	5/19/2015	7.3x10-6 Torr	125C
3.15 pm	5/19/2015	4.4x10-6 Torr	125C
3.55 pm	5/19/2015	4.0x10-6 Torr	125C
5.45 pm	5/19/2015	3.6x10-6 Torr	125C
5.49 am	5/20/2015	~3.6 x 10-6 Torr	125C
8.50 am	5/20/2015	2.0x10-6 Torr	70C

Measurements are realized using the Anritsu Site Master Broadband Cable and Antenna analyzer S820D

Measurements of the Reflection coefficients (S/N:4)

After outgassing.
Quick verification.





Measurements are realized using the Anritsu Site Master Broadband Cable and Antenna analyzer S820D

Thermal-cycling and deployment at -60 °C

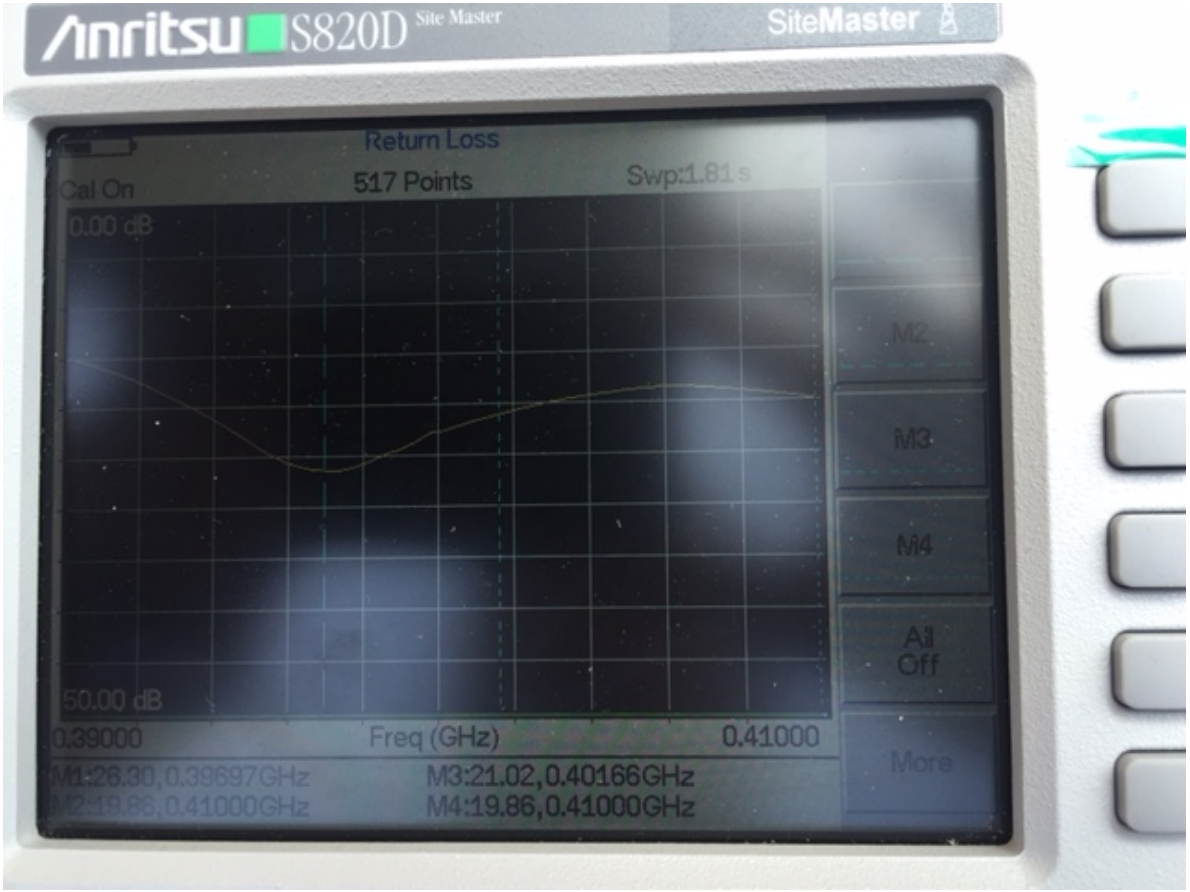
- 3 temperatures cycles covering the range of -130° C +125 ° C of the cable mounted with the antenna.
- One antenna is deployed using the burn wiring mechanism at -60 °C.

Stowed

Deployed

Measurements of the Reflection coefficients (S/N:4)

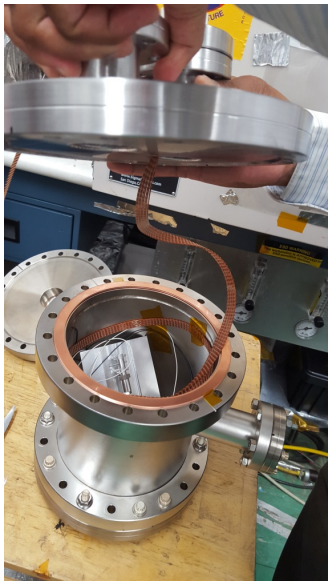
After outgassing and
thermal-cycling.
Quick verification.

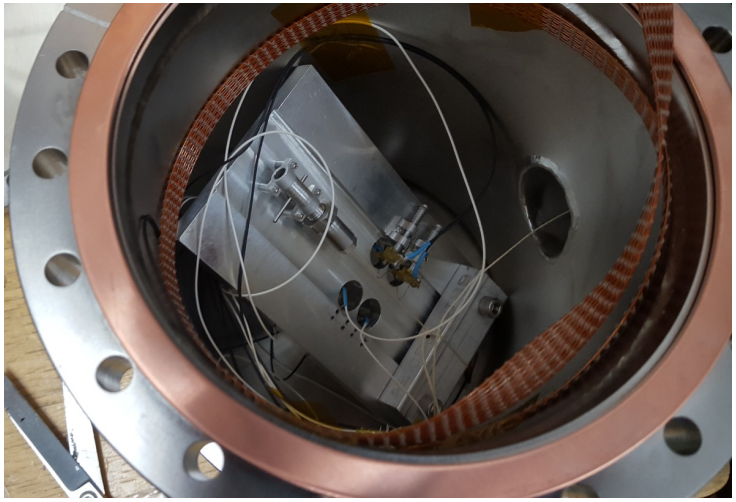


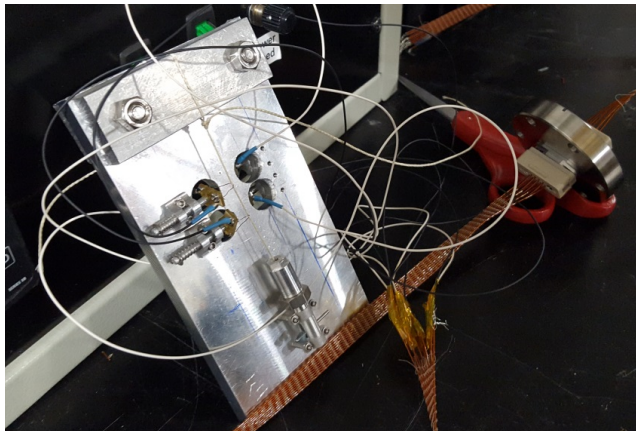
Measurements are realized using the Anritsu Site Master Broadband Cable and Antenna analyzer S820D

Verification of the current necessary to deploy

Requirement: DC voltage/current applied 1.6 A for 2-10 sec.



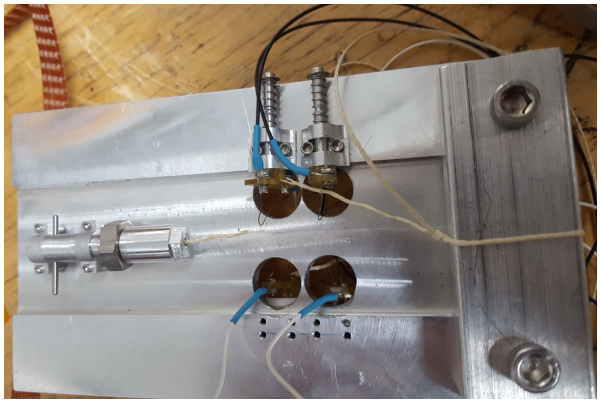


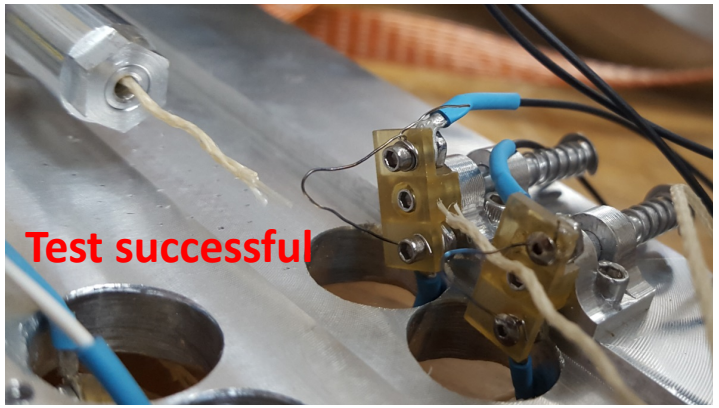


Tie-down wire was cut using 1.6 Amp current on the power supply

The burn wire test was realized in vacuum (<10^{-5} Torr) at both the temperature extremes expected in space at the time of deployment:

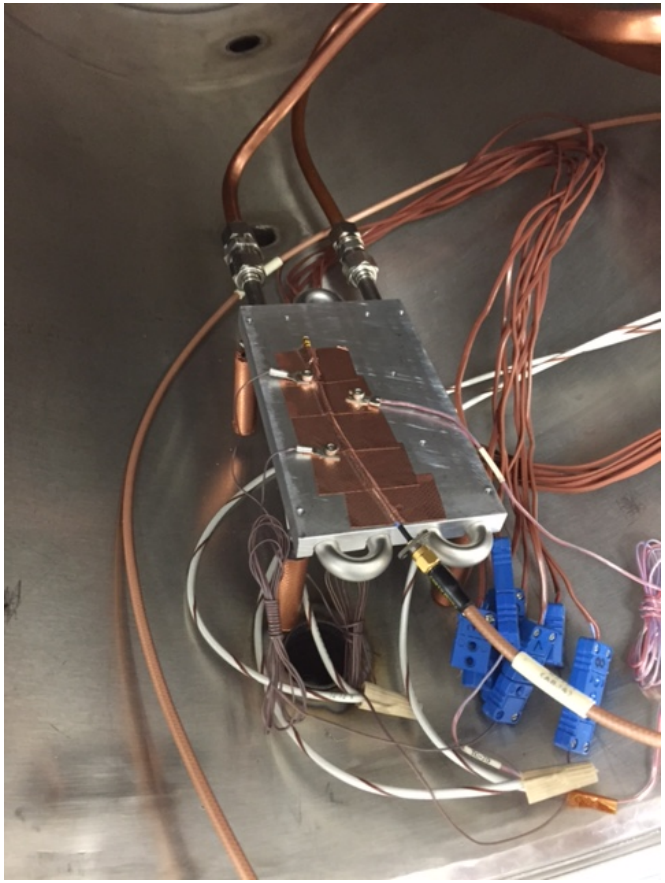
- 55°C
+ 125° C

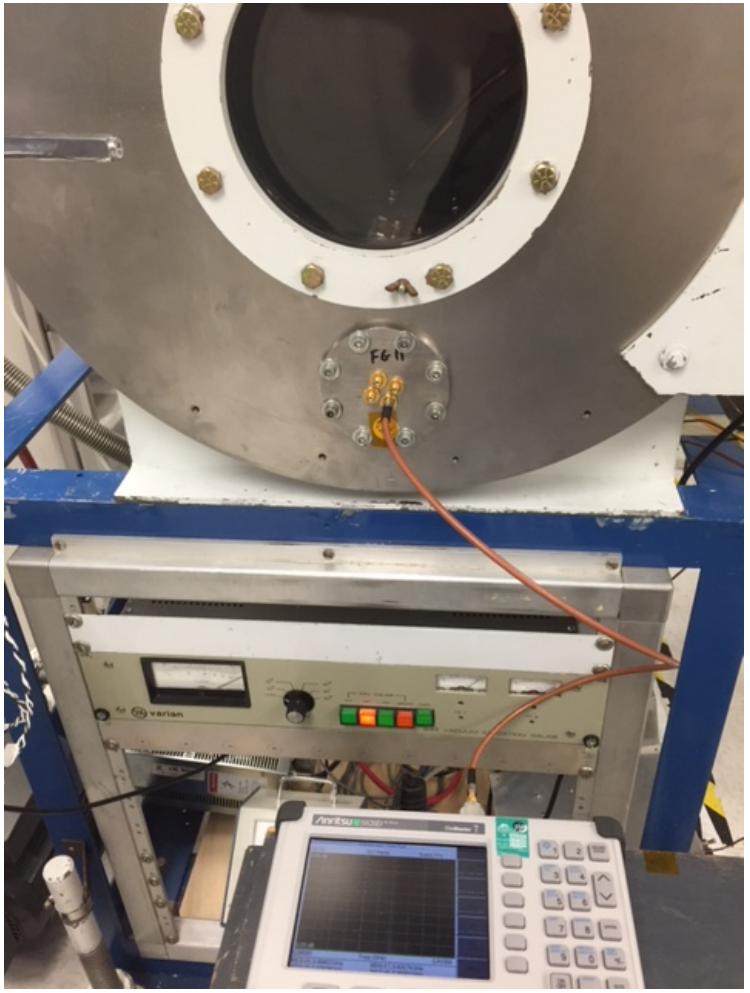




Insertion loss of the cable at both extreme temperature

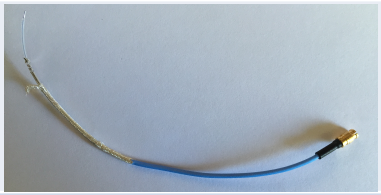
- **In vacuum (<10^{-6} Torr), Insertion loss measured at +125°C 0.14dB ±0.01 and at - 130°C 0.10dB ±0.01.**





Measurements are realized using the Anritsu Site Master Broadband Cable and Antenna analyzer S820D

Summary Coaxial thermal tests

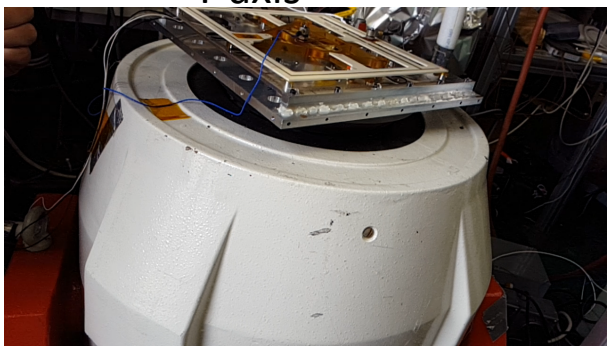
status	Insertion loss (dB)*
As received from the manufacturer (6 cables)	0.12 ±0.01
After Thermal-cycling (7.5 x ± 130° C) (after several mechanical deployment test) (S/N:6)	0.15 ±0.01
After outgassing (FM cables S/N:1-5)	0.16 ±0.01
After Thermal-cycling (FM cables S/N 1-5) (3x -130°C +125°C)	0.14 ±0.01
After several mechanical deployment tests (FM flight S/N:4)	0.17 ±0.01
Peel off cable (S/N: 5) to investigate the origin of the stiffness in the cable.	
Measured at both extreme temperature in vacuum (S/N:6)	@ +125°C: 0.14 dB ±0.01 @ -130°C: 0.10 dB ±0.01

In general, a degradation of ~30% in the cable performance is observed. However, the cable will most likely work at -130°C while operating in space.

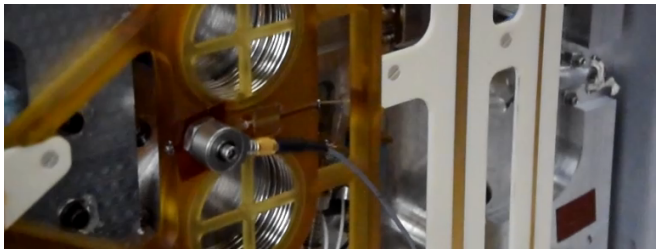
*All measurements are realized using the Anritsu Site Master Broadband Cable and Antenna analyzer S820D

Reflection coefficients after vibe

Y-axis



X-axis



Z-axis